AP Physics - Unit 2 - Dynamics

NATIONAL MATH + SCIENCE INITIATIVE

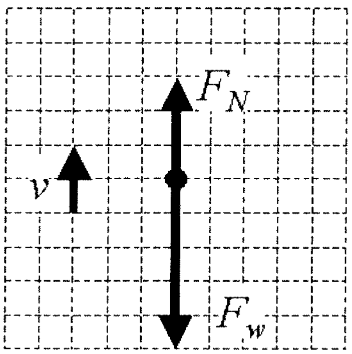
# AP PHYSICS 1

## Wkst - Forces on a Single Object # 2

## Pre-Assessment Questions

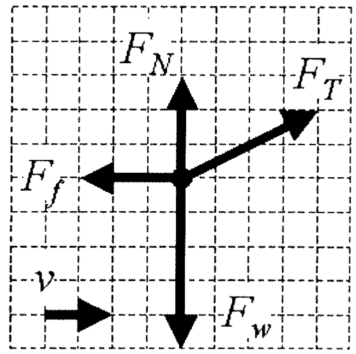
The dots below represent three objects that have weight ($F_W$), normal ($F_N$), friction ($F_f$), and tension ($F_T$) forces acting on them, or the force applied by a human hand ($F_A$). If the object is moving, then a velocity vector $v$ is shown near the dot. For each of the three cases, describe in words a situation where an object could feel those forces and have the motion indicated. Draw a picture diagram. Write equations for Newton's First Law (N-1) or Newton's Second Law (N-2) as asked. * Hint - 1st Law - No Net force
2nd Law acceleration = Net force

**P1.**




N-2 Eq$^n$: ________________

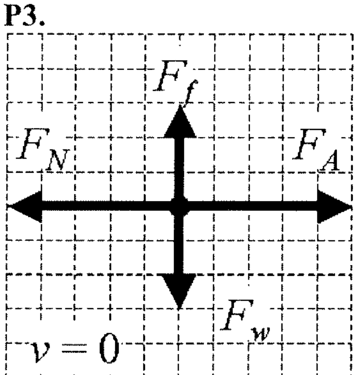
**P2.**




N-1 Eq$^n$: ________________

N-2 Eq$^n$: ________________

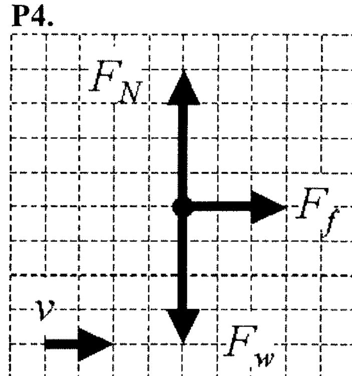
**P3.**




N-1 Eq$^n$: ________________

N-1 Eq$^n$: ________________

**P4.**




N-1 Eq$^n$: ________________

N-2 Eq$^n$: ________________

**Force** is a physical quantity that measures and models a "push" or a "pull". All forces have an **object** (thing that the force acts on) and an **agent** (thing that is doing the pushing or pulling). For example, you have a weight force. For that weight force, the object is you and the agent is Earth.

Force can be measured based on its strength, and the strength of a force is measured in units called newtons (unit symbol: N). Force is a vector, which means that every force has a direction associated with it. Forces that act in the same direction act together to create a stronger force, whereas forces acting in opposite directions create a weaker force. When all the forces on an object are added up (as vectors with their directions considered), we obtain the **net force** on the object. (Note: We call it "net force" and not "total force", because the word "net" implies a total but where *some numbers could be negative*. Forces are negative if they point in a negative direction, such as left or down.)

Forces can be classified into these types:

| Name | Symbol | Direction | Equation (if any) |
|---|---|---|---|
| Weight | $F_w$, $F_g$, or $W$ | Down (toward the center of Earth) | $F_w = mg$ |
| Normal | $F_N$ or $N$ | Perpendicular to the surface | |
| Tension | $F_T$ or $T$ | Parallel to the rope | |
| Static Friction | $F_{fs}$ or $f_s$ | Parallel to the surface | $F_{fs} \leq \mu_s F_N$ |
| Kinetic Friction | $F_{fk}$ or $f_k$ | Parallel to the surface | $F_{fk} = \mu_k F_N$ |
| Spring | $F_s$ | Parallel to the spring's axis | $F_s = kx$ |

**A note about friction**: This is a wrong statement: "Friction opposes motion." The correct statement is actually "Friction opposes *sliding*." Sometimes friction opposes sliding by *causing motion to happen* (yes, I just said that sometimes friction causes motion). Consider a runner competing in a 100-m dash. Suppose the starting signal is given, but the runner starts on a slab of ice. The runner would slip and fall on his face and not go anywhere. This slipping would occur because there is not enough friction to prevent the slipping. Real track athletes wear cleats in order to increase the amount of friction between their shoes and the track so that their shoes don't slip and they can speed up effectively. **When friction helps you move, you call it *traction*, but it is still the same thing as friction.**

**Newton's Laws**: Newton's first two laws of motion deal with the forces that act on a single object. These two laws are *often stated incorrectly*. Please forgive us if we are contradicting anything that you have been taught, but it is for your own good. From this point forward, everything marked with a ☺ is the "right way to think" and everything marked with a ☹ is the "wrong way to think".

**Newton's First Law** deals with a single object whose forces all add to zero.
☹ "An object in motion stays in motion & an object at rest stays at rest unless acted upon by an outside force."
☺ **If there is no net force on an object, then the object moves with constant velocity.**

What's wrong with the ☹? It assumes there are only two possibilities: an object has no forces on it or an object has only one force on it. No object in the universe that has zero or one forces acting on it (you have two right now: normal and weight). This statement is also too vague about how an object moves when it has "no force".

What should I take from the ☺?

- The individual forces don't matter, what matters is the *net force*.
- Newton's First Law deals with the situation where all the forces balance, making the *net force* zero.
- Velocity is speed with direction, so "constant velocity" means that the object has a speed that doesn't change and, if moving, moves in a direction that doesn't change.

- Standing still counts as constant velocity—it is a velocity that is constantly zero.
- Moving with a constant speed in a straight-line path is also constant velocity.
- The law is biconditional, which means "**If an object moves with constant velocity, then there is no net force on the object**" is also a true statement (the law is correct forwards and backwards).

**Newton's Second Law** deals with a single object whose forces do not add to zero.
☹ "Force equals mass times acceleration. $F = ma$."
☺ **An object's acceleration is the result of the net force on the object divided by the object's mass.**

$$\vec{a} = \frac{\vec{F}_{net}}{m}.$$

What's wrong with the ☹? Again, "force" implies only one force. Newton's Laws don't care about any one individual force; all that matters is the *net force* that results from all the forces acting together. Also, "$F = ma$" makes you think that force is determined by mass and acceleration—this is not the correct cause-and-effect relationship among these quantities.

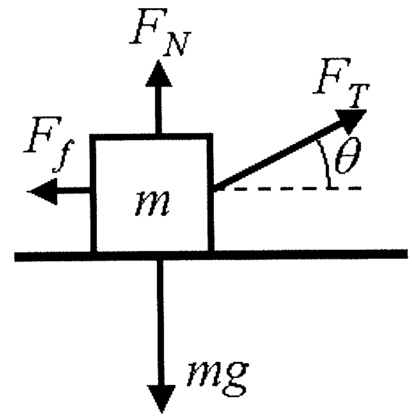
What should I take from the ☺?
- The individual forces don't matter, what matters is the *net force*.
- Newton's First Law deals with the situation where the forces DON'T balance, making a *net force*.
- The law is expressed as $\vec{a} = \frac{\vec{F}_{net}}{m}$ because your math teachers have brainwashed you into thinking "what is on the left depends on what is on the right". If you're going to believe this, then we write the law as $a = F_{net}/m$ so you understand that acceleration (change in motion) depends on what is doing the pushing ($F_{net}$) and what is being pushed ($m$).

Newton's first two laws can be summarized in these sentences: ***An object's motion changes in proportion to the net force acting on the object.***

## Building Equations From Free-Body Diagrams

Once a free-body diagram is drawn, we must write one or more equations that relate the forces and express Newton's Laws. The steps are as follows:
- Determine the direction of the object's acceleration, but don't draw acceleration on the FBD.
- If there is any force that is not parallel and not perpendicular to acceleration, make parallel and perpendicular components out of that force.
- Make an equation where forces perpendicular to acceleration balance out and equal each other.
- Make an equation where forces parallel to acceleration sum to *ma*.

Example: the box accelerates to the right. Friction is parallel to **a**, and weight and normal are perpendicular to **a**, but tension needs to be broken into two components: $F_T\sin\theta$ up and $F_T\cos\theta$ to the right.

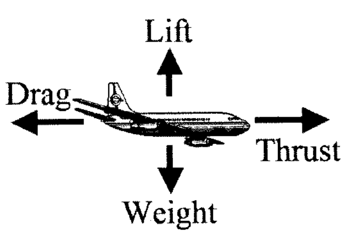


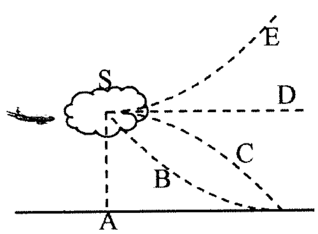

- Weight is down, normal and $F_T\sin\theta$ are up, and since these forces are perpendicular to **a**, they balance each other out: $F_N + F_T\sin\theta = mg$
- $F_T\cos\theta$ is in the same direction as **a**, so it is a "positive" force. Friction opposes **a**, so it is a "negative" force. Because these forces are parallel to **a**, they add to $ma$: $F_T\cos\theta - F_f = ma$

## Multiple-Choice Questions

**M1.** *Apollo 13* is a 1995 movie about a mission to the Moon that experiences serious problems. In the movie, an astronaut says, "We just put Sir Isaac Newton in the driver's seat." This line, a reference to Newton's First Law, is spoken just after

(A) the rocket begins firing its engines and lifts off from the launch pad.
(B) the spacecraft begins firing its engines on its way back to Earth from the Moon.
(C) the spacecraft enters Earth's atmosphere and air resistance begins to slow its descent.
(D) the spacecraft has finished firing its engines and has spent all of its fuel.

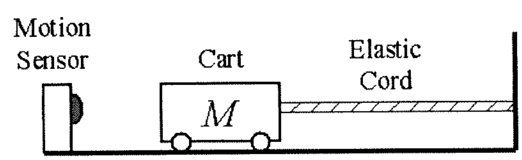



**M2.** An aircraft flying to the right has a constant horizontal speed of 200 m/s has four forces acting on it shown above left. When the aircraft passes through the cloud at point S (shown above right), the force of thrust has the same magnitude as the force of drag, and the force of lift balances the force of weight. If this condition continues, which path shown above right will the plane follow?

**M3.** A skydiver falling through the air opens her parachute. The skydiver and parachute together have a weight $W$. At a specific instant after the parachute opens, the force of air resistance on the parachute is $1.4W$. What is the acceleration of the parachute-and-skydiver system at this instant?

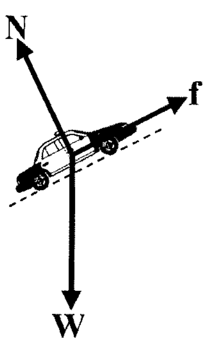
(A) 14 $m/s^2$ downward
(B) 4 $m/s^2$ downward
(C) 4 $m/s^2$ upward
(D) 14 $m/s^2$ upward

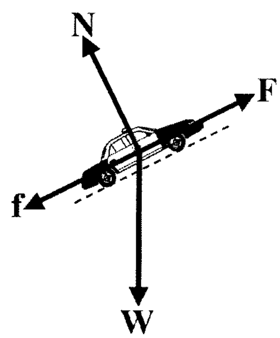


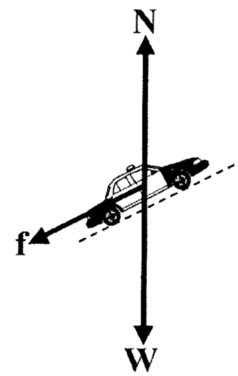

**M4.** A student hypothesizes that a certain elastic cord exerts a constant force even as the cord contracts to its natural length. To test this hypothesis, the student attaches the cord to a cart and stretches the cord a significant distance. The student releases the cart and measures the increase in speed $\Delta v$ of the cart during an interval of time $\Delta t$. If the student performs multiple trials in which the mass $M$ of the cart is varied, which of the following graphs would yield a line if the cord's force were constant?

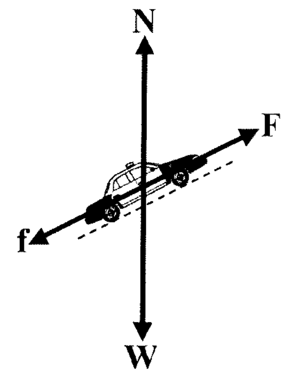
(A) $M$ vs. $(\Delta v/\Delta t)$
(B) $M$ vs. $(\Delta t/\Delta v)$
(C) $M^2$ vs. $(\Delta v/\Delta t)$
(D) $M^2$ vs. $(\Delta t/\Delta v)$

**M5.** A car travels up a hill at constant speed. Which of the following diagrams best represents the forces acting on the car at this instant?

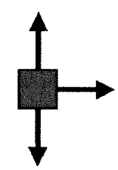
(A)



(B)



(C)



(D)


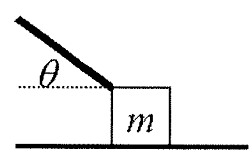

**M6.** Three forces of equal magnitude act on the box shown. One force is upward, one downward, and one rightward. Which of the following statements must be true based on this information? Select two answers.



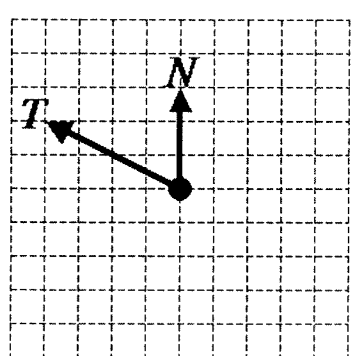
(A) The box must have a rightward component of velocity.
(B) The box has no vertical component of velocity.
(C) The acceleration of the box is directed to the right.
(D) The velocity of the box is changing with time.

## Free-Response Questions

**F1.** A block of mass $m$ is pulled along a rough horizontal surface by a rope that exerts a constant tension force at a constant angle $\theta$ with the vertical. The block accelerates to the left.




(a) The dot below represents the block as it accelerates to the left. The tension and normal forces are already drawn and labeled to-scale using the grid in the background. Draw the weight $W$ and friction $f$ acting on the block. Use the grid to draw each force an appropriate length relative to the other two forces.

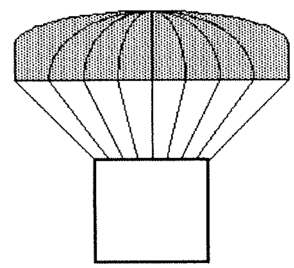



(b) Suppose that the force of tension is kept at constant strength, but the angle $\theta$ is increased but kept less than $90^{\circ}$. Student $A$ predicts that the block's leftward acceleration will decrease as a result of the increased angle. Student $B$ predicts that the block's leftward acceleration will increase as a result of the increased angle.

i. Using appropriate physical principles and relationships, explain how student *A* could be correct.

ii. Using appropriate physical principles and relationships, explain how student *B* could be correct.

**F2.** A student is given the toy shown, which is a small, light box attached to a parachute. The student knows that there is a relationship between the upward force exerted by air on the parachute and the downward speed of the box-parachute system. The student wishes to experimentally determine whether the force of air is directly proportional to fall speed. The student has access to a tape measure, stopwatch, electronic balance, and a large bucket of sand.



(a) In the space below, outline a procedure that the student could follow in order to make measurements that could be used to determine whether the force of air resistance is directly proportional to fall speed. Be sure to explain how each piece of equipment is to be used.

(b) Explain how the measurements made in part (a) can be used to determine whether the force of air resistance is directly proportional to fall speed.

(c) Suppose that the student takes the data shown in the table below.

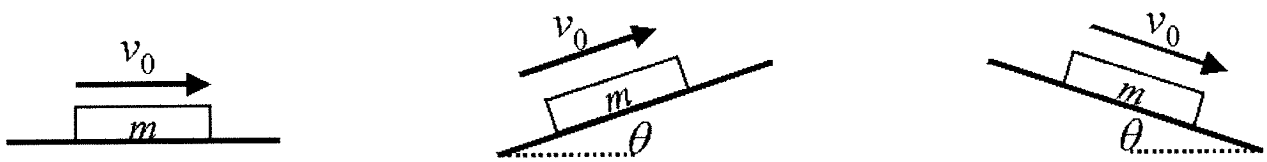
| Force of Air (N) | 2.0 | 4.0 | 6.0 | 8.0 | 10.0 |
|---|---|---|---|---|---|
| Fall Speed (m/s) | 2.1 | 3.0 | 3.7 | 4.2 | 4.7 |

Based on these data, is there a directly-proportional relationship between force of air and fall speed? Explain your reasoning.

Skip (d) Once the box-and-parachute system is released, the system quickly reaches a constant speed. Answer the following for a time interval that the box travels with constant speed.

i. Is the net work being done on the box positive, negative, or zero during this interval? Explain your reasoning.

ii. Is the net work being done on the box-Earth system positive, negative, or zero during this interval? Explain your reasoning.

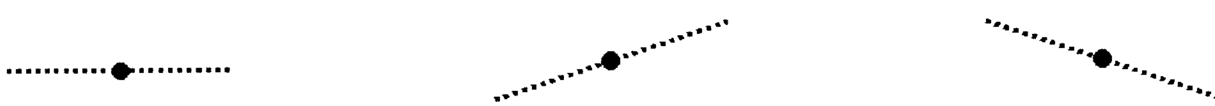



Trial 1 Trial 2 Trial 3

**F3.** A student performs an experiment in which a block is set on a track and given a short push so that its initial speed is $v_0$. The student performs three experimental trials: in Trial 1 the track is horizontal, in Trial 2 the track is set at an angle $\theta$ with the horizontal so that the block slides uphill, and in Trial 3 the track is set at an angle $\theta$ with the horizontal so that the block slides downhill. In all three cases, friction between the block and the track brings the block to rest.

(a) Each dot below represents the block as it slows down during each trial. For each trial, draw and label the forces (NOT components) acting on the block as it slows to rest. The dotted line represents the incline and is shown for reference.

Trial 1 Trial 2 Trial 3



(b) In which trial is the frictional force acting on the block the greatest in magnitude? Explain your reasoning.

(c) Derive an expression for the magnitude of the block's acceleration in trial 2 in terms of coefficient of kinetic friction between the track and incline $\mu$, the angle of the track $\theta$, and the acceleration of gravity $g$.

The student observes that the block slides the farthest before coming to rest in Trial 3, and slides the shortest distance before coming to rest in Trial 2.

(d) Explain why this is the case. Use your responses to parts (a) through (c) to support your explaination.

(e) On the axes below, draw three graphs of velocity vs. time for the block, one graph for each of the three trials. Label your graphs "1", "2", and "3" to correspond to each trial.